U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE
SUBCOMMITTEE ON RESEARCH

HEARING CHARTER

Nanotechnology: Where Does the U.S. Stand?

Wednesday, June 29, 2005
10:00 a.m. - Noon
2318 Rayburn House Office Building

1. Purpose

On Wednesday, June 29, 2005, the Research Subcommittee of the Committee on Science of the House of Representatives will hold a hearing to examine the findings and recommendations of the recent assessment of the National Nanotechnology Initiative (NNI) by the President's Council of Advisors on Science and Technology (PCAST) and will hear from the nanotechnology community on how U.S. research and business activities in nanotechnology measure up to those of international competitors.

2. Witnesses

Mr. Floyd Kvamme is the Co-Chair of the President's Council of Advisors on Science and Technology and a partner at Kleiner Perkins Caufield & Byers, a high-technology venture capital firm.

Mr. Jim O'Connor is Vice President of Technology Incubation and Commercialization at Motorola, Inc.

Mr. Sean Murdock is the Executive Director of the NanoBusiness Alliance.

Mr. Matthew M. Nordan is the Vice President of Research at Lux Research Inc., a nanotechnology research and advisory firm.

3. Overarching Questions

- What is the position of U.S. research and development and U.S. businesses in nanotechnology relative to that of other countries? What key factors influence U.S. performance in the field, and what trends exist among those factors?

- Which fields of science and engineering present the greatest opportunities for breakthroughs in nanotechnology, and which industries are most likely to be altered by those breakthroughs in both the near-term and the longer-term?

- What are the primary barriers to commercialization of nanotechnology, and how can these barriers be overcome or removed? What is the federal government's role in facilitating the commercialization of nanotechnology innovations, and how can the current federal nanotechnology program be strengthened in this area?

4. Brief Overview

- In December 2003, the President signed the *21st Century National Nanotechnology Research and Development Act* (P.L. 108-153), which originated in the Science Committee. This Act provided a statutory framework for the interagency National Nanotechnology Initiative (NNI), authorized appropriations for nanotechnology research and development (R&D) activities through fiscal year 2008 (FY08), and enhanced the coordination and oversight of the program. Funding for the NNI has grown from $464 million in fiscal year 2001 (FY01) to $1.1 billion in FY05, and 11 agencies currently have nanotechnology R&D programs.

- In addition to federal investments, state governments and the private sector have become increasingly involved in supporting nanotechnology. In 2004, the private sector in the U.S. invested roughly $2 billion in nanotechnology research, while state and local governments invested roughly $400 million. The state and local investment is primarily spent on infrastructure and research at public universities, while the private funding focuses on applied research and development activities at small and large companies, and funding for start-up nanotechnology ventures.

- Other countries are also investing significant funds in nanotechnology research and development. In 2004, governments in Europe, Japan, and elsewhere spent approximately $2.8 billion in this area, and corporations outside North America spent roughly $2 billion.

- The *21st Century National Nanotechnology Research and Development Act* required that a National Nanotechnology Advisory Panel (NNAP) biennially report to Congress on trends and developments in nanotechnology science and engineering and on recommendations for improving the NNI. The first such report was released in May 2005 (the executive summary is attached). Its recommendations include strengthening federal-industry and federal-state cooperation on nanotechnology research, infrastructure, and technology transfer, and broadening federal efforts in nanotechnology education and workforce preparation.

5. Background

Overview of Nanotechnology

The National Academy of Sciences describes nanotechnology as the "ability to manipulate and characterize matter at the level of single atoms and small groups of atoms." An Academy report describes how "small numbers of atoms or molecules ... often have properties (such as strength, electrical resistivity, electrical conductivity, and optical absorption) that are significantly different from the properties of the same matter at either the single-molecule scale or the bulk scale." Scientists and engineers anticipate that nanotechnology will lead to "materials and systems with dramatic new properties relevant to virtually every sector of the economy, such as medicine, telecommunications, and computers, and to areas of national interest such as homeland security."[1]

Nanotechnology is an enabling technology and, as such, its commercialization does not depend specifically on the creation of new products and new markets. Gains can come from incorporating nanotechnology into existing products, resulting in new and improved versions of these products. Examples could include faster computers, lighter materials for aircraft, less invasive ways to treat cancer, and more efficient ways to store and transport electricity. Some less-revolutionary nanotechnology-enabled products are already on the market, including stain-resistant, wrinkle-free pants, ultraviolet-light blocking sunscreens, and scratch-free coatings for eyeglasses and windows.

In October 2004, Lux Research, a private research firm, released its most recent evaluation of the potential impact of nanotechnology. The analysis found that, in 2004, $13 billion worth of products in the global marketplace incorporated nanotechnology. The report projected that, by 2014, this figure will rise to $2.6 trillion—15 percent of manufacturing output in that year. The report also predicts that in 2014, ten million manufacturing jobs worldwide—11 percent of total manufacturing jobs—will involve manufacturing these nanotechnology-enabled products.[2]

National Nanotechnology Initiative

The National Nanotechnology Initiative (NNI) is a multi-agency research and development (R&D) program. The goals of the NNI, which was initiated in 2000, are to maintain a world-class research and development program; to facilitate technology transfer; to develop educational resources, a skilled workforce, and the infrastructure and tools to support the advancement of nanotechnology; and to support responsible development of nanotechnology. Currently, 11 federal agencies have ongoing programs in nanotechnology R&D; funding for those activities is shown in Table 1. Additionally, 11 other agencies, such as the Food and Drug Administration, the U.S. Patent and Trademark Office, and the Department of Transportation, participate in the coordination and planning work associated with the NNI.

[1] *Small Wonders, Endless Frontiers: A Review of the National Nanotechnology Initiative,* National Research Council/National Academy of Sciences, 2002.
[2] Lux Research, "Sizing Nanotechnology's Value Chain," October 2004.

Table 1. Funding for the National Nanotechnology Initiative (Dollars in Millions)

	FY04 Actual	FY05 Estimated	FY06 Proposed
National Science Foundation	256	338	344
Department of Defense	291	257	230
Department of Energy	202	210	207
National Institutes of Health	106	142	144
National Institute of Standards and Technology	77	75	75
National Aeronautics and Space Administration	47	45	32
Environmental Protection Agency	5	5	5
National Institute for Occupational Safety & Health	0	3	3
U.S. Department of Agriculture	2	3	11
Department of Justice	2	2	2
Department of Homeland Security	1	1	1
Total	**989**	**1081**	**1054**

Source: The National Nanotechnology Initiative—Supplement to the Presidents FY06 Budget Request

In 2003, the Science Committee wrote and held hearings on the *21st Century National Nanotechnology Research and Development Act*, which was signed into law on December 3, 2003. The Act authorizes $3.7 billion over four years (FY05 to FY08) for five agencies (the National Science Foundation, the Department of Energy, the National Institute of Standards and Technology, the National Aeronautics and Space Administration, and the Environmental Protection Agency). The Act also: adds oversight mechanisms—an interagency committee, annual reports to congress, an advisory committee, and external reviews—to provide for planning, management, and coordination of the program; encourages partnerships between academia and industry; encourages expanded nanotechnology research and education and training programs; and emphasizes the importance of research into societal concerns related to nanotechnology to understand the impact of new products on health and the environment.

National Nanotechnology Advisory Panel Report

The *21st Century National Nanotechnology Research and Development Act* required the establishment or designation of a National Nanotechnology Advisory Panel (NNAP) to assess and provide advice on the NNI. In July 2004, the President designated the existing President's Council of Advisors on Science and Technology to serve as the NNAP. The NNAP's responsibilities include providing input to the administration on trends and developments in nanotechnology and on the conduct and management of the NNI.

The NNAP is required to report to Congress on its activities every two years, and its first report was formally released in May 2005. (The executive summary of this report is included in

Appendix A, its content is described below, and the full report is available online[3].) The report assesses the U.S. position in nanotechnology relative to the rest of the world, evaluates the quality of current NNI programs and program management, and recommends ways the NNI could be improved.

Benchmarking

The NNAP report finds that U.S. leads the rest of the world in nanotechnology as measured by metrics such as level of spending (both public and private), publications in high-impact journals, and patents. The report also finds, however, that other countries are increasing their efforts and investments in nanotechnology and are closing the gap with the U.S.

Nanotechnology is a relatively new field, and relevant activities in the U.S. and abroad are focused more on research and development than on production and sales. The NNAP observes that, because the relevant markets are still emergent, useful economic indicators, such as market share, are not yet available for the evaluation of the U.S. competitive position. Therefore, the NNAP report considers where the U.S. stands by examining benchmarks such as funding for nanotechnology research and development and numbers of publications and patents.

Reliable data on spending is difficult to gather, as definitions of nanotechnology vary, and investments in the private sector are often not reported. Information gathered by the National Science Foundation demonstrates that funding for nanotechnology around the world has grown significantly over the past decade or so; specifically, while total government investment in nanotechnology research and development was roughly $430 million in 1997, by 2005 it had climbed to roughly $4.1 billion—a factor of 10 increase in just eight years. The U.S. traditionally has accounted for just over a quarter of that spending. Japan and the European Union countries collectively each spend roughly the same amount as the U.S.

There is less historical data available for private sector spending on nanotechnology research and development, but current data are gathered. The most recent analysis from Lux Research estimates that corporations worldwide spent $3.8 billion in this area in 2004, with 46 percent ($1.7 billion) of that spent by North American companies, 36 percent ($1.4 billion) by Asian companies, 17 percent ($650 million) by European companies, and less than 1 percent by companies from other regions. In addition, venture capital firms invested approximately $400 million in nanotechnology start-up companies.

Data on spending describe current levels of effort and hence information about future generation of knowledge. Data on publications and patents provide a sense of the level of recent innovations and advances. Analysis of the U.S. share of publications show that, while the U.S. produces the most papers in nanotechnology, both overall and in the most highly-regarded journals, the percent of such papers originating in the U.S. is declining as other countries' contributions grow more rapidly than those from the U.S. Similar trends can be seen in studies of patents awarded.

[3] The PCAST's report, *National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel*, is available online at http://www.nano.gov/FINAL_PCAST_NANO_REPORT.pdf.

One of the reasons that the U.S. is the acknowledged leader in nanotechnology is its breadth of investment; research and development activities are ongoing in areas relevant to a wide range of industries (such as materials, energy, electronics, health care, etc.). Most other countries cannot afford to invest as broadly as the U.S. Some of these other countries—particularly in Asia—have chosen to concentrate their investments in particular areas to make strides in a specific sector. For example, Korea and Taiwan are investing heavily in nanoelectronics while Singapore and China are focusing on nanobiotechnology and nanomaterials, respectively.

NNI Management

The NNAP report finds that the NNI is a well managed program. The report notes that the balance of funding among different areas of nanotechnology is appropriate and emphasizes the importance of investment in a diverse array of fields rather than a narrow focus on a just a few "Grand Challenges." In particular, the NNAP lauds the NNI for advancing the foundational knowledge about control of matter at the nanoscale; creating an interdisciplinary nanotechnology research community and an infrastructure of over 35 nanotechnology research centers, networks, and user facilities; investing in research related to the environment, health, safety, and other societal concerns; establishing nanotechnology education programs; and supporting public outreach.

Recommendations

The NNAP recommends continued strong investment in basic research and notes the importance of recent federal investment in research centers, equipment, and facilities at universities and national laboratories throughout the country (see Appendix B). Such facilities allow both university researchers and small companies to have access to equipment too expensive or unwieldy to be contained in an individual laboratory.

The NNAP also emphasizes the importance of state and industry contributions to the U.S. nanotechnology efforts and recommends that the NNI expand federal-state and federal-industry interactions through workshops and other methods.

The NNAP also recommends that the federal government actively use existing government programs such as the Small Business Innovation Research (SBIR) and the Small Business Technology Transfer (STTR) programs to enhance technology transfer in nanotechnology. All grant-giving agencies are required by law to have SBIR and STTR programs, and some of them specifically target solicitations toward nanotechnology. However, it is hard to get a clear, up-to-date picture of how much funding is actually provided for nanotechnology-related projects in these programs and on what the demand for SBIR/STTR funding in this area is. The NNAP also recommends that federal agencies be early adopters and purchasers of new nanotechnology-related products in cases where these technologies can help fulfill an agency's mission.

The NNAP also finds that the NNI is making good investments in environmental, health, and safety research, and recommends that the federal government continue efforts to coordinate this work with related efforts in industry and at non-profits and with activities conducted in other

countries. The NNAP emphasizes the importance of communication with stakeholders and the public regarding research and findings in this area.

Finally, the NNAP emphasizes the importance of education and workforce preparation and recommends that the NNI coordinate with Departments of Education and Labor to improve access to materials and methods being developed for purposes of nanotechnology education and training.

Challenges Ahead

The NNAP notes that successful adoption of nanotechnology-enabled products will require coordination between federal, state, academic, and industrials efforts (including for efficient commercialization of products), training of a suitable high-technology workforce, and development of techniques for the responsible manufacture and use of these products.

Developing a federal strategy to facilitate technology transfer of nanotechnology innovations is a particularly complex challenge because of the wide range of industry sectors that stand to benefit from nanotechnology and the range of time scales at which each sector will realize these benefits. The NNAP report provides examples of various possible nanotechnology applications and when they are expected to reach the product stage (Table 2). The applications cover sectors from information technology and health care to security and energy, and some applications are on the market now, while others are more than 20 years in the future.

Table 2: Areas of Opportunity for Nanotechnology Applications

Time Scale	**Nanotechnology Applications**
Near-term (1-5 years)	- Nanocomposites with greatly improved strength-to-weight ratio, toughness, etc. - Nanomembranes and filters (including for water purification and desalination) - Improved catalysts with one or more orders of magnitude less precious metal - Sensitive, selective, reliable solid-state chemical and biological sensors - Point-of-care medical diagnostic devices - Long-lasting, rechargeable batteries
Mid-term (5-10 years)	- Targeted drug therapies - Enhanced medical imaging - High efficiency, cost effective solar cells - Improved fuel cells - Efficient technology for water-to-hydrogen conversion - Carbon sequestration
Long-term (20+ years)	- Drug delivery through cell walls - Molecular electronics - All-optical information processing - Neural prosthetics for treating paralysis, blindness, etc. - Conversion of energy from thermal or chemical sources in the environment

Source: Report of the National Nanotechnology Advisory Panel (2005)

As the NNAP report notes, the states are playing an increasing role in nanotechnology. In 2004, state funding for nanotechnology-related projects was $400 million, or approximately 40 percent of the total federal investment. To date, state funding for nanotechnology has been focused on infrastructure—particularly the construction of new facilities—with some research support being provided in the form of matching funds to public universities that receive federal research dollars. In addition to receiving state support, universities and national laboratories also leverage federal investments through industry contributions of funds or in-kind donations of equipment and expertise. The NNAP report lists 15 examples of nanotechnology infrastructure investments at the state and local levels, and further details on non-federal initiatives can be found in the recent report on a 2003 NNI workshop on regional, state, and local nanotechnology activities.[4]

In recent years, the focus has been on the construction of nanotechnology facilities, but as these building projects financed by federal, state, and private funding are completed, the nanotechnology community must consider how best to capitalize on these new resources. Specifically, funding will have to be found for operating expenses, and policies that will attract public and private sector users to these facilities will be needed on topics such as collaboration, intellectual property, and usage fees.

The diversity of industry sectors will be a challenge for developing appropriate education and workforce training programs in nanotechnology. The predicted scale and breadth of research and manufacturing jobs related to nanotechnology will require not only specialized programs but also integration of nanotechnology-related information into general science, technology, engineering, and mathematics education.

Finally, successful integration of nanotechnology into products will require an understanding of the standards and regulations needed to govern responsible manufacturing and use of nanotechnology-enabled products. Under the FY06 budget request, $82 million (8 percent) of the proposed NNI R&D funding would be spent on research related to the societal implications of nanotechnology. Of this amount, $38.5 million (4 percent of the overall program) would be specifically directed at environmental, health, and safety research, while the remainder is for the study of economic, workforce, educational, ethical, and legal implications. In addition to this funding, relevant work is also ongoing in other NNI focus areas. One example is the development of measurement techniques at the nanoscale which are necessary to set standards that can be used for quality control of nanotechnology products and to manage compliance with safety regulations. Another example is the study of the basic mechanisms of interaction between nanoscale materials and biological systems, which can provide critical information for health care applications as well as safe use practices.

[4] *Regional, State, and Local Initiatives in Nanotechnology* is the report on a workshop convened on September 30 – October 1, 2003 by the Nanoscale Science, Engineering and Technology (NSET) Subcommittee, the interagency group that coordinates NNI activities. The report is available online at http://www.nano.gov/041805Initiatives.pdf.

6. Witness Questions

The witnesses were asked to address the following questions in their testimony:

Questions for Mr. Floyd Kvamme:

- What is the position of U.S. research and development in nanotechnology relative to that of other countries? What key factors influence U.S. performance in the field, and what trends exist among those factors?
- What fields of science and engineering present the greatest opportunities for breakthroughs in nanotechnology, and what industries are most likely to be affected by those breakthroughs in both the near-term and the longer-term?
- What is the federal government's role in facilitating the commercialization of nanotechnology innovations, and how can the current federal nanotechnology program be strengthened in this area?
- What is the workforce outlook for nanotechnology, and how can the federal government help ensure there will be enough people with the relevant skills to meet the nation's needs for nanotechnology research and development and for the manufacture of nanotechnology-enabled products?

Questions for Mr. Jim O'Connor:

- What is the position of U.S. research and development in nanotechnology relative to that of other countries? What key factors influence U.S. performance in this field?
- What fields of science and engineering present the greatest opportunities for breakthroughs in nanotechnology relevant to Motorola, and what products are most likely to be affected by those breakthroughs in both the near-term and the longer-term?
- What countries and corporations do you perceive to be your closest competitors in nanotechnology science and business? What factors influence Motorola's ability to compete with these groups?
- What is the workforce outlook for nanotechnology, and how does the U.S. position compare to that of other countries? How can the federal government help ensure there will be enough people with the relevant skills to meet the nation's needs for nanotechnology research and development and for the manufacture of nanotechnology-enabled products?

Questions for Mr. Sean Murdock:

- What is the position of U.S. businesses in nanotechnology relative to that of other countries? What key factors influence U.S. performance in the field, and what trends exist among those factors?
- What investments are other countries making in nanotechnology research, development, and commercialization activities? How do other countries' approaches differ from that of the U.S.?
- What industries are most likely to be affected by breakthroughs in nanotechnology in both the near-term and the longer-term?
- What are typical pathways by which ideas or prototypes of new nanotechnology-related products or processes are successfully developed into commercial applications? What are the primary barriers to these pathways, and how can these barriers be overcome or removed?

- What is the federal government's role in facilitating the competitiveness of U.S. industry in nanotechnology, and how can the current federal nanotechnology program be strengthened in this area?

Questions for Mr. Matthew Nordan:

- What is the position of U.S. businesses in nanotechnology relative to that of other countries? What key factors influence U.S. performance in the field, and what trends exist among those factors?
- What investments are other countries making in nanotechnology research, development, and commercialization activities? How do other countries' approaches differ from that of the U.S.?
- What industries are most likely to be affected by breakthroughs in nanotechnology in both the near-term and the longer-term?
- What are typical pathways by which ideas or prototypes of new nanotechnology-related products or processes are successfully developed into commercial applications? What are the primary barriers to these pathways, and how can these barriers be overcome or removed?
- What is the federal government's role in facilitating the competitiveness of U.S. industry in nanotechnology, and how can the current federal nanotechnology program be strengthened in this area?

Appendix A

The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel

Report to the President from the President's Council of Advisors on Science and Technology
Released May 2005, full report available online at http://www.nano.gov/FINAL_PCAST_NANO_REPORT.pdf

EXECUTIVE SUMMARY

The President's Fiscal Year (FY) 2004 Budget, released in February 2003, tasked the President's Council of Advisors on Science and Technology (PCAST) with reviewing the National Nanotechnology Initiative (NNI) and making recommendations for strengthening the program. Congress ratified the need for an outside advisory body with its passage of the 21st Century Nanotechnology Research and Development Act of 2003 (the Act), which called for the President to establish or designate a National Nanotechnology Advisory Panel (NNAP). By Executive Order, the President designated PCAST as the NNAP in July 2004. To augment its own expertise in managing large research and development (R&D) programs, PCAST identified a Technical Advisory Group (TAG) comprising about 45 nanotechnology experts representing diverse disciplines and sectors across academia and industry. The TAG is a knowledgeable resource, providing input and feedback with a more technical perspective.

The Act calls upon the NNAP to assess the NNI and to report on its assessments and make recommendations for ways to improve the program at least every two years. This is the first such periodic report provided by PCAST in its role as the NNAP.

The Administration has identified nanotechnology as one of its top R&D priorities. When FY 2005 concludes later this year, over 4 billion taxpayer dollars will have been spent since FY 2001 on nanotechnology R&D. In addition, the President's FY 2006 Budget includes over $1 billion for nanotechnology research across 11 Federal agencies. Such a substantial and sustained investment has been largely based on the expectation that advances in understanding and harnessing novel nanoscale properties will generate broad-ranging economic benefits for our Nation. As such, the NNAP members believe the President, the Congress, and the American people are seeking answers to four basic questions relative to the Federal investment in nanotechnology R&D:

1. **Where Do We Stand?**
2. **Is This Money Well Spent and the Program Well Managed?**
3. **Are We Addressing Societal Concerns and Potential Risks?**
4. **How Can We Do Better?**

Answers to these questions provide the assessments and recommendations called for by the Act. Our conclusions can be summarized as follows:

1. Where Do We Stand? Today, the United States is the acknowledged leader in nanotechnology R&D. The approximately $1 billion annual Federal Government funding for nanotechnology R&D is roughly one-quarter of the current global investment by all nations.

Total annual U.S. R&D spending (Federal, State, and private) now stands at approximately $3 billion, one-third of the approximately $9 billion in total worldwide spending by the public and private sectors. In addition, the United States leads in the number of start-up companies based on nanotechnology, and in research output as measured by patents and publications. Our leadership position, however, is under increasing competitive pressure from other nations as they ramp up their own programs.

2. Is This Money Well Spent and the Program Well Managed? The NNAP members believe strongly that the money the United States is investing in nanotechnology is money very well spent, and that continued robust funding is important for the Nation's long-term economic well-being and national security. Nanotechnology holds tremendous potential for stimulating innovation and thereby enabling or maintaining U.S. leadership in industries that span all sectors. The focus of the NNI on expanding knowledge of nanoscale phenomena and on discovery of nanoscale and nanostructured materials, devices, and systems, along with building an infrastructure to support such studies, has been both appropriate and wise. The NNI has accomplished much already—advancing foundational knowledge, promoting technology transfer for commercial and public benefit, developing an infrastructure of user facilities and instrumentation, and taking steps to address societal concerns—and the economic payoffs over the long term are likely to be substantial.

The NNI appears well positioned to maintain United States leadership going forward, through both its coordinated interagency approach to planning and implementing the Federal R&D program and its efforts to interact with industry and the public. This approach is outlined clearly in the recently released NNI Strategic Plan, which spells out the goals and priorities for the initiative for the next 5 to 10 years. The NNAP members believe that this Plan provides an appropriate way to organize and manage the program.

3. Are We Addressing Societal Concerns and Potential Risks? The societal implications of nanotechnology—including environmental and health effects—must be taken into account simultaneously with the scientific advances being underwritten by the Federal Government. The NNI generally recognizes this, and is moving deliberately to identify, prioritize, and address such concerns.

Environmental, Health, and Safety. The NNAP convened a panel of experts from Government regulatory agencies, academia, and the private sector to discuss the environmental and health effects of nanotechnology. Based on these panel discussions, as well as on information received from the NSET Subcommittee and the TAG, the NNAP members believe that potential risks do exist and that the Government is directing appropriate attention and adequate resources to the research that will ensure the protection of the public and the environment. The NNAP members are particularly pleased that strong communication exists among the agencies that fund nanotechnology research and those responsible for regulatory decision-making.

Education. The future economic prosperity of the United States will depend on a workforce that both is large enough and has the necessary skills to meet the challenges posed by global competition. This will be especially important in enabling the United States to maintain its leadership role in nanotechnology and in the industries that will use it. The NNI has launched a

range of education-related programs appropriate for classrooms at all levels and across the country, along with other programs that are aimed at the broader public. While the NNI cannot be expected to solve the Nation's science education problems singlehandedly, the NNAP members believe that these NNI activities can help improve science education and attract more bright young minds into careers in science and engineering.

Other Societal Dimensions. Understanding the impact of a new technology on society is vital to ensuring that development takes place in a responsible manner. In addition to research into societal issues such as the environmental, health, and safety effects of nanotechnology, the NNI's diverse and growing R&D program is exploring other issues such as economic, workforce, and ethical impacts. In addition, communication among the various stakeholders and with the public on these topics is an important element of the program, as indicated by the establishment of an interagency subgroup to address this topic.

4. How Can We Do Better? The NNAP will monitor progress on the program elements discussed above; in the meantime, the NNAP offers the following recommendations aimed at further strengthening the NNI.

Technology Transfer. The level of interest and investment across many industrial sectors is growing and will likely outpace Government investment in the United States soon, if it hasn't already. The NNI needs to take further steps to communicate and establish links to U.S. industry to further facilitate technology transfer from the lab to the marketplace. The NNAP calls attention to two areas that would augment the existing suite of activities and enhance commercialization of research results.

- **The NNI's outreach to, and coordination with, the States should be increased.** Such efforts would complement those NNI activities already underway with various industrial sectors. The States perform a vital role in fostering economic development through business assistance programs, tax incentives, and other means. In addition, collectively the States are spending substantial amounts in support of nanotechnology R&D and commercialization. The NNAP members believe that practical application of NNI-funded research results, workforce development, and other national benefits will increase with improved Federal-State coordination.

- **The NNI should examine how to improve knowledge management of NNI assets.** This would include assets such as user facilities and instrumentation available to outside researchers, research results, and derivative intellectual property. Through mechanisms such as publicly available and searchable databases, the NNI can—and should—improve infrastructure utilization and the transfer of technology to the private sector.

The NNAP notes that, although ultimate commercialization of nanotechnology is desirable and to be supported, the NNI must remain mindful that its primary focus is on developing an understanding of the novel properties that occur at the nanoscale and the ability to control matter at the atomic and molecular level. While we all want the United States to benefit economically from nanotechnology as quickly as possible, it is critically important that the basic intellectual

property surrounding nanotechnology be generated and reside within this country. Those who hold this knowledge will "own" commercialization in the future.

Environmental and Health Implications. The NNI should continue its efforts to understand the possible toxicological effects of nanotechnology and, where harmful human or environmental effects are proven, appropriate regulatory mechanisms should be utilized by the pertinent Federal agencies. Nanotechnology products should not be immune from regulation, but such regulation must be rational and based on science, not perceived fears. Although it appears that the public and the environment are adequately protected through existing regulatory authorities, the NNAP encourages the Government regulatory agencies to work together to ensure that any regulatory policies that are developed are based on the best available science and are consistent among the agencies.

The NNAP notes that research on the environmental and health implications of nanomaterials and associated products should be coordinated not only within the Federal Government, but with other nations and groups around the world to ensure that efforts are not duplicated unnecessarily and information is shared widely.

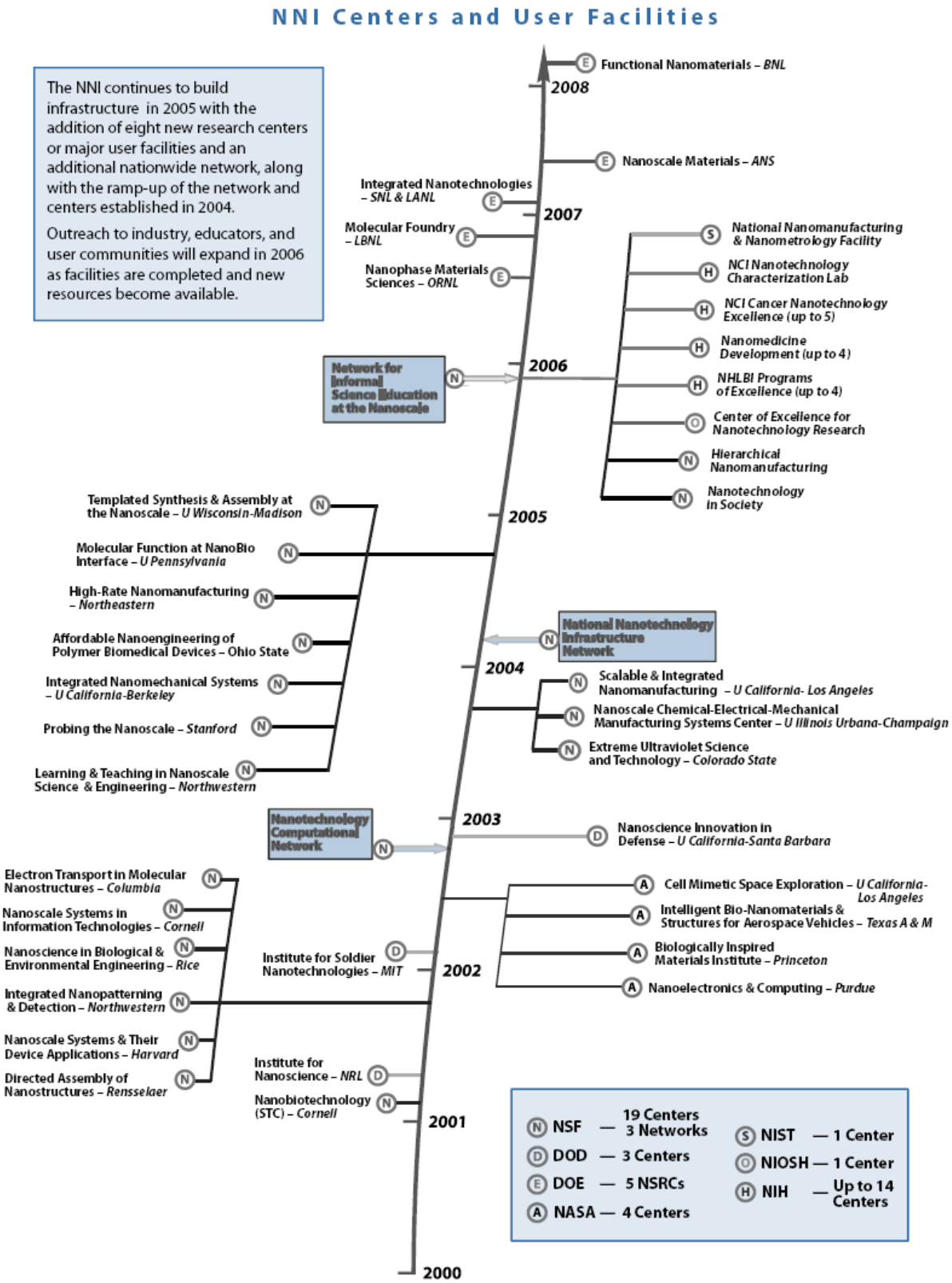
Education/Workforce Preparation. A key to realizing the economic benefits of nanotechnology will be the establishment of an infrastructure capable of educating and training an adequate number of researchers, teachers, and technical workers. To maximize the value of its investment in developing materials and programs for education and worker training, the NNI should establish relationships with the Departments of Education and Labor. While the science agencies such as the National Science Foundation can conduct education research and design excellent programs and materials, ultimately the mission agencies, Education and Labor, must be engaged to disseminate these programs and materials as widely as possible throughout the Nation's education and training systems.

The NNI's education focus should be on promoting science fundamentals at K-16 levels, while encouraging the development and incorporation of nanotechnology-related material into science and engineering education. To promote mid-career training for professionals, the NNI should partner with and support professional societies and trade associations that have continuing education as a mission.

Societal Implications. The NNI must support research aimed at understanding the societal (including ethical, economic, and legal) implications and must actively work to inform the public about nanotechnology. Now more than ever, those who are developing new scientific knowledge and technologies must be aware of the impact their efforts may have on society.

In summary, the NNAP supports the NNI's high-level vision and goals, and the investment strategy by which those are to be achieved. Panel members feel that the program can be strengthened by extending its interaction with industry, State and regional economic developers, the Departments of Education and Labor, and internationally, where appropriate. The NNI should also continue to confront the various societal issues in an open, straightforward, and science-based manner.

Appendix B: National Nanotechnology Initiative Centers and User Facilities



Source: The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel